The Dalhousie Privateers

Dalhousie Engineering
2010 MATE International ROV Competition
Explorer Class

The Team
Alex Parker, Andrea Felling, Chris Brake, Dainis Nams, Gina Marin, Irenee Jantz-Lee, Janis Nams, Jonathan Leahey, Kathleen Svendson, Matthew Mallay, Michael Marchand, Neil McPherson, Peter Pearl, Phil Dixon, Piotr Kawalec, Scott Holmes, Sebastien Bourdage, Terrence Abramson, Timothy Pohajdak

Mentors
Dr. G. Jarjoura, Dr. C. Watts, Dr. Mae Seto, Reg Peters

Contents

Acknowledgments

We would like to sincerely thank our sponsors who have generously supported us this year:

- **Ultra Electronics Maritime Systems**
- **Shell Canada**
- GeoSpectrum
- Department of Engineering of Dalhousie University
- The Binnacle
- Spar Marine Ltd
- Institute of Electrical and Electronics Engineers
- Stantec Engineering
- Dominion Diving
- SubSea Consultants
- Engineers Nova Scotia
- Dalhousie Student Union
- Dalhousie Undergraduate Engineering Society
- Jentronics
- Vemco-Amirix
- Fleetway Inc.
- LED Roadway Lighting Ltd.

In addition we would also like to thank our mentors for all the help they have given us throughout the year keeping us both on course and target:

Dr. George Jarjoura, Dr. Chris Watts, Dr. Mae Seto, and Reg Peters.

Finally, we would like to send a special thanks to Dr. Joshua Leon, Dr. Larry Hughes, Mr. Glenn Macleod, Mr Angus MacPherson, and all of our friends and family without whom we would not have been able to complete this project.

Abstract

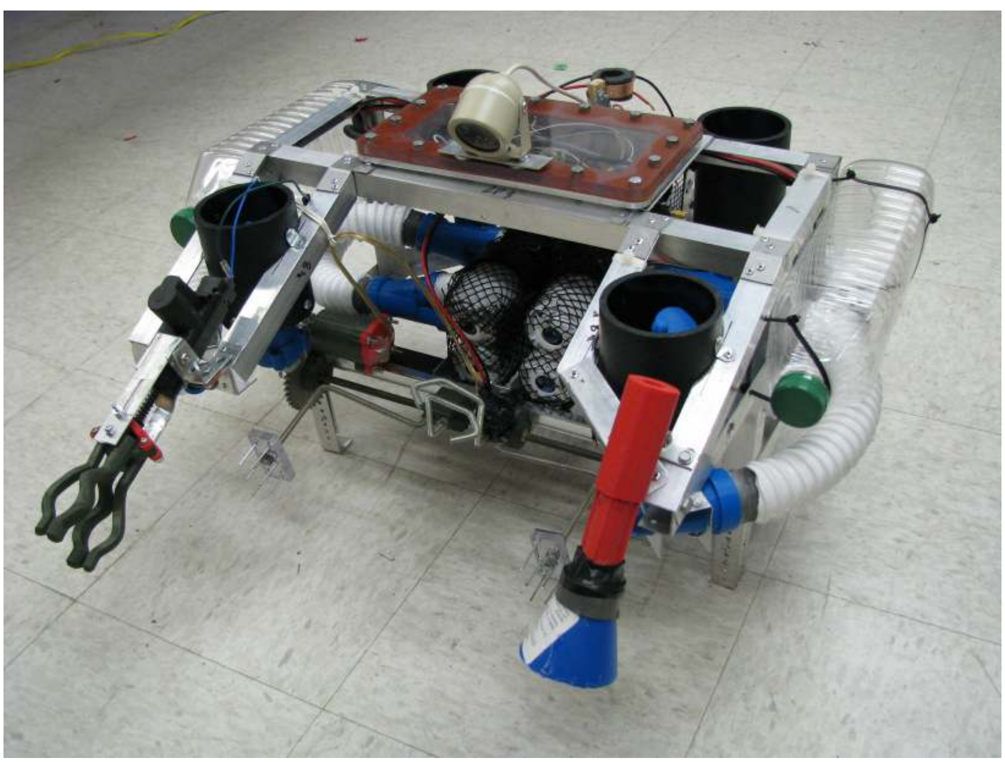
This document details the Dalhousie Privateers' entry in the 2010 MATE International ROV Competition and outlines the design rationale and methodologies used in the development of our craft. This year's missions center around the exploration of unknown waters, and who better to perform such a task than the Privateers. The goal of this year's design was to once again to create both an innovative tooling system as well as a lightweight manoeuvrable craft. The Privateers have continued our tradition of having team members complete all of the vehicle planning, design, and programming themselves and as much of the construction as possible.

Our compact and light aluminium frame is designed to have a small footprint while catering to our tooling and housing the motivational motors. The drive system consists of four small vertical propeller motors and eight Rule 1100 bilge pumps arranged in a horizontal vector drive format, providing the craft with superior speed and handling performance in comparison to our previous designs.

Our on board electronics are housed in a custom aluminium box capped with a bolt-on acrylic lid for easy visual inspection. In addition to the on-board electrical system we have created a custom $48V_{DC}$ power distribution system for testing and a command console housing our controlling computer and camera display monitors. Our in house software uses control input from an Xbox 360 controller connected to the PC in our command console to interface with a PIC microcontroller on the ROV.

The Privateers' are extremely proud to present our third entry into a MATE International ROV competition:

THE ALUMINIUM FALCON



The Crew

Once again the Privateers have returned to MATE's International Competition in order to pursue our true love of gold. This year's ships complement is the largest to date as we continue to source new recruits from the first and second years of the engineering program as well as attract a few more seasoned veterans from the upper years of the program.

Officers

Admiral Peter Pearl (Project Director) – 4th Year Electrical
Captain Dainis Nams (Chief Engineer) – 4th Year Mechanical
Mr. Chris Brake (Mechanical Lead) – 3rd Year Mechanical
Mr. Sebastien Bourdage (Electrical Lead) – 3rd Year Electrical

Deck Hands

Mr. Alex Parker – 2nd Year Electrical
Ms. Andrea Felling – 2nd Year Mechanical
Ms. Gina Marin – 2nd Year Mechanical
Ms. Irenee Jantz-Lee – 2nd Year Electrical
Mr. Janis Nams – 1st Year Core
Mr. Jonathan Leahey – 4th Year Mechanical
Ms. Kathleen Svendson – 2nd Year Computer
Mr. Matthew Mallay – 1st Year Core
Mr. Michael Marchand – 4th Year Mechanical
Mr. Neil McPherson – 2nd Year Electrical
Mr. Phillip Dixon – 2nd Year Materials
Mr. Piotr Kawalec – 3rd Year Mechanical
Mr. Scott Holmes – 2nd Year Mechanical
Mr. Terrence Abramson – 1st Year Core
Mr. Timothy Pohajdak – 4th Year Mechanical

Project Budget

Qty	Item	Cost Per Unit	Total	Source	Purchased /Donated
Power Box					
10	DPDT 12V Relays	15	150	Digikey	Purchased
1	12Vdc Charger	60	60	Princess Auto	Purchased
1	Emergency Stop SW	6.59	6.59	Princess Auto	Purchased
1	Master Power Switch	13.99	13.99	Princess Auto	Purchased
1	120Vac to 12Vdc Power Adaptor	8.99	8.99	Princess Auto	Purchased
2	Spools 12 Guage Wire	19.99	39.98	Princess Auto	Purchased
1	Crimp on Connector Kit	30.59	30.59	Princess Auto	Purchased
1	Ammeter	6.99	6.99	Princess Auto	Purchased
1	VoltMeter	6.99	6.99	Princess Auto	Purchased
1	TIP31 Transistor	0.75	0.75	Department Electrical engineering	Donated
8	Sealed Lead Acid 12V batteries	20	160	Ebay	Purchased
1	40 Amp Breaker	4.99	4.99	Princess Auto	
Command Center					
3	10" Monitors	229.99	689.97	ID Lab	Donated
1	ECM 3610	354.99	354.99	ID Lab	Donated
1	X-Box 360 Controller Generic	49.99	49.99	Last Game Store	Purchased
1	40 Amp Breaker	4.99	4.99	Princess Auto	Purchased
1	Enermax 300Watt Power Supply	70	70	GreenLyph Computers	Purchased
1	Toggle Switch	3.99	3.99	Princess Auto	Purchased
Tether					
1	3 Stranded Power Cable 12	30	30	DRDC	Donated
1	50 Foot of CATV	16.99	16.99	GreenLyph Computers	Purchased
2	3 Pin Through Hole Marine Grade Power Connector Set	59.99	119.98	DRDC	Donated
2	CATV Through Hole Marine Grade Connector Set	20.99	41.98	ID Lab	ID Lab
On Board Electronics					
1	EUMFD60Y12A DC DC Converter	434.74	434.74	Digikey	Purchased
4	Fish TV Cameras	120	480	Cabela Sports	Purchased
3	Wide Angle CCD Cameras	19.99	59.97	Ebay	Purchased
1	PIC32	5.99	5.99	Digikey	Purchased
3	Bi-Directional Motor Driver IC	13.99	41.97	Digikey	Purchased
14	Fast Recovery Diodes	1.34	18.76	Department Electrical engineering	Donated
1	Bi-Directional Level Translator	3.53	3.53	Department Electrical engineering	Donated
Frame, Propulsion, & Tooling					
8	RULE 1100GPM Bilge Pump	27.8	222.4	The Binnacle	Purchased
60	1" x 1/16" angle aluminium (1 foot)	0.69	41.4	Metals R Us	Puchased
1	6" x 4" x 12" stock aluminium	92.3	92.3	Metals R Us	Purchased
8	Johnson 12Vdc motor	6.99	55.92	Princess Auto	Purchased
80	Rapid Prototyping Material (priced per cubic inch)	6	480	Dalhousie University	Donated
1	Thermally Conductive Potting Compound	139.98	139.98	Jentronics	Donated
	Nuts, Bolts, Washers, etc		300	Various	Purchased
	Props Construction		250	Various	Purchased
	Tooling Prototyping		250	Various	Purchased
	TOTAL		$4,750		

The Construction of the Aluminium Falcon

The Frame

The *Falcon's* basic shape, as seen in Figure 1, was developed with the intent of allowing it to accomplish all task #1 elevator missions from one stationary position. The frame was built using 1" by 1/16" angle aluminium. This material was chosen because it is light, easy to work with, and would provide easy 90° angle mounting points for attachments.

The frame construction process was much more complex than in previous years due to our integrated frame and tooling approach to the mission tasks. First, a rough prototype was built from plastic construction pieces to check the ROV's interaction with the mission props in full-scale 3D. Once the general chassis shape was confirmed, we drafted a fully dimensioned version from which to build a prototype aluminium frame.

We installed all subsystems in the prototype frame and conducted pool tests to determine which aspects of the frame could still use improvement. After these trials we built the final version of the frame with minor adjustments including easier tool mount points and larger water columns below the vertical thrusters.

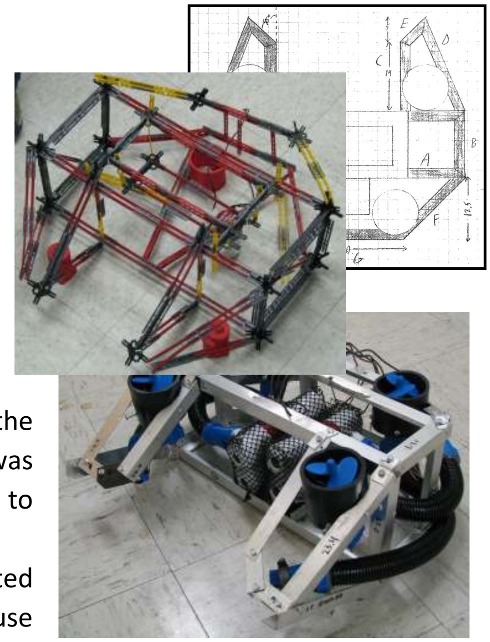


Figure 1: Frame Progression

Propulsion Systems

The propulsion system for the *Aluminium Falcon* consists of two distinct subsystems: a lift system consisting of four small $12V_{DC}$ motors equipped with custom waterproof cases and propellers and a horizontal system using eight Rule 1100 bilge pumps. This provides the *Falcon* with significant horizontal thrust and fine lateral control.

Vertical

The thruster casing, as seen in Figure 2, was designed to both mount and waterproof a Johnson $12V_{DC}$ motor. The casing was designed using SolidEdge and made from ABS plastic using a stereolithography rapid prototyper. The casing incorporates a press-in shaft seal, an O-ring sealed endcap, and threaded inserts for mounting purposes. A thick bulkhead section in the cap has two solid copper wires melted through to provide a watertight electrical connection. Finally, the sealed case is filled with mineral oil which provides cooling for the DC motor as well as ensures that water cannot quickly leak inside in the event of seal failure.

The thruster system incorporates a cowling made out of a 3" ABS pipe for increased thrust and safety purposes. The motor shaft is threaded to accommodate any small propeller. The custom bidirectional propellers were designed for maximum efficiency and printed on the rapid prototyper.

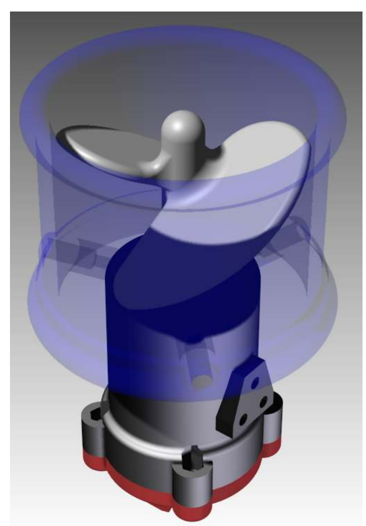


Figure 2: Vertical Thruster

Horizontal

For horizontal propulsion, the team decided to use a vector propulsion system similar to last year's. This system allows for horizontal translation in any direction and rapid rotation. The vector propulsion system consists of bilges pumps in the center of the craft and nozzles pointed 45 degrees at each corner as shown in Figure 3.

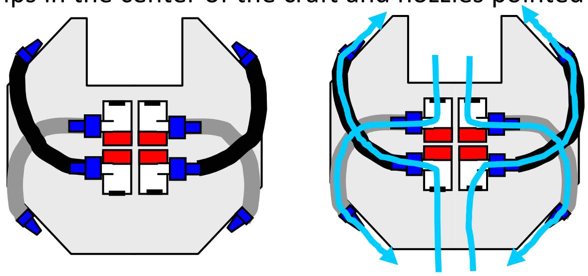


Figure 3: Vector System

The largest change that has been made to the system is a reduction in the number of nozzles. In previous years, eight bilge pumps were connected to eight nozzles (two at each corner), resulting in a great deal of the ROV's footprint being dedicated to tubing. This year the team has added a joiner piece to the system which merges the output of two bilge pumps into a single tube leading to a single nozzle, as shown in Figure 4 and Figure 5.

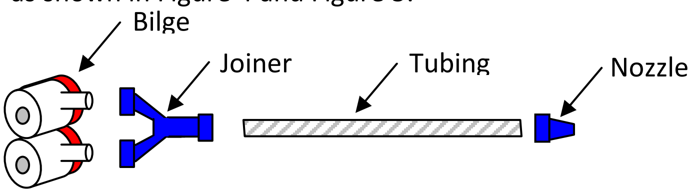


Figure 5: Individual Components of the Vector System

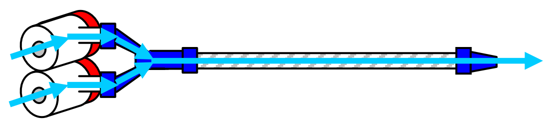


Figure 4: Flow Through System

In order for the ROV to move in a straight line, two neighbouring nozzles must be activated, as detailed in Figure 6. The force vectors sum in the desired direction and cancel in other directions, leaving a net resultant vector forward, back, left or right – whichever the case may be. For clockwise or counter-clockwise rotation, the operator simply activates nozzles on opposite corners, creating two moment arms that sum together. Refer to *Appendix A – Vector Propulsion System Performance* for a detailed fluid mechanics analysis of the performance and efficiency of our vector propulsion system.

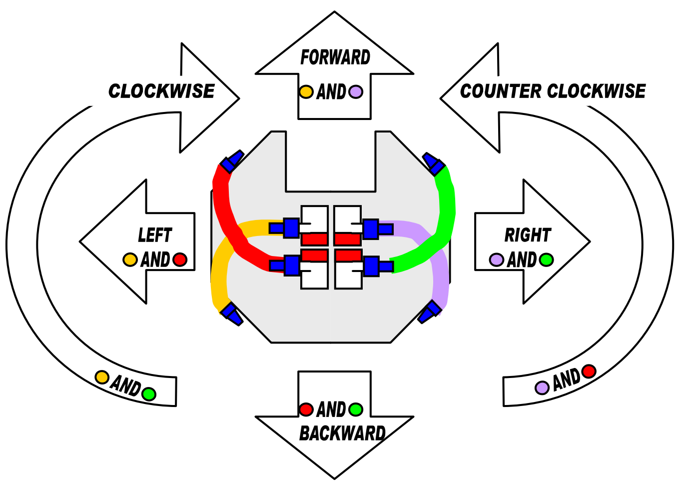


Figure 6: Activation Patterns for Driving the ROV

Electronics Housing

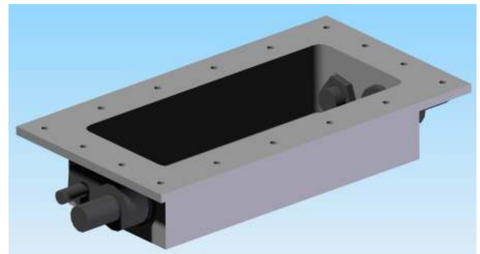


Figure 7: Electronics Box

The housing for the onboard electronics is an open-top box constructed from a single milled block of aluminium, a rim gasket, and a clear acrylic lid. Aluminium was chosen for its strength, low weight, and good heat conductivity. The acrylic lid was chosen to allow easy viewing of the components inside. Spacers hold the electronics above the box floor to protect them in the event of a slow water leak. Waterproof connectors were chosen over permanently sealed electrical connections to facilitate easy tether removal. As seen in Figure 7, the box was modeled using Solid Edge software to allow a 3D inspection confirming component layout. The CAD model was used to guide a CNC milling machine as it cut the box from a single block of stock aluminium.

Tether

This year the team focussed on a light, flexible tether design to provide maximum manoeuvrability within the confines of the cave. The *Falcon's* 20 meter tether consists of a marine-grade power cable, a CAT-5E Ethernet cable, and a parachute cord. The power cable provides $48V_{DC}$ to the ROV. The Ethernet cable allows for ROV control signals, sensor data recovery, and video feed recovery. Lastly, the parachute cord serves as the tether's strength member and point of physical attachment on the *Falcon.*

Onboard Electronics

The heart of the *Falcon's* wet side electronics is a PIC32 micro-controller operating at 80 MHz. This controller was chosen because of Micro-chip's DSP library. This library contains pre-built fast Fourier algorithms that allow for processing of the analog signals being produced by the vent rumblers. In addition to signal processing, this chip controls all of the propulsion and tooling motors on the *Falcon*.

The on board controller was developed around the PIC32 to ensure maximum system efficiency.
The board consists of six major building blocks:

- 1 X Power module
- 1 X Differential Communications module
- 6 X Uni-directional modules
- 3 X Bi-Directional modules
- 2 X 8:1 Video control modules
- 1 X Instrumentation section

The power module of the system consists of two major sections:

- Main Power Module
- Control Board Power Module

Main Power Module

Due to DC power losses inevitable over such a long tether, the Privateers made the decision to make the 48 to $12V_{DC}$ conversion on board the ROV. As shown in Figure 8, a EUMFD60Y12A DC to DC converter was used.

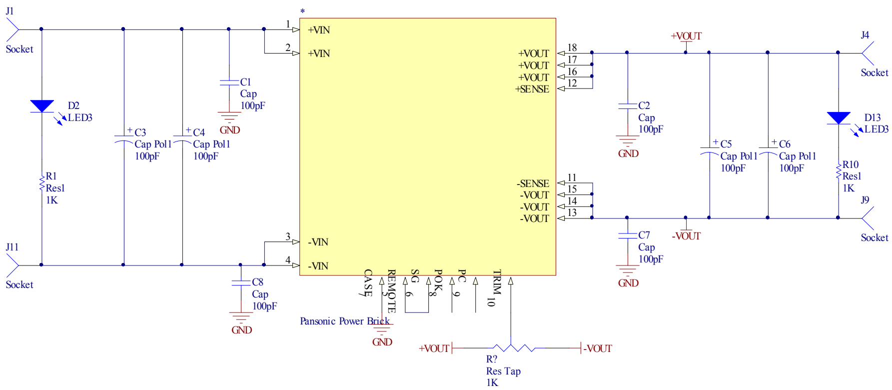


Figure 8: DC to DC Converter Controlling Circuit

This allows the transmission of power to the ROV using at higher voltages and lower currents in order to reduce line loss due to the length of the tether. On board the $48V_{DC}$ is converted to a full $12V_{DC}$, which is then used to power the on board system. This conversion ensures that the motors can receive a full $12V_{dc}$ which is important as power is directly proportional to the square of the voltage. The calculations below show that the loss of a single volt on a 12V system results in over a 15% reduction in power. important as power is directly proportional to the square of the voltage. As seen in Equation 1, the loss of a single volt on a 12V system results in over a 15% reduction in power.

$$P = \frac{V^2}{R} \rightarrow \text{ if only } \frac{11}{12} \text{Voltage available then } \rightarrow P = \frac{\left(\frac{11}{12}V\right)^2}{R} = \frac{\frac{121}{144}V^2}{R} \approx \frac{0.84V^2}{R}$$

Equation 1: Voltage Losses

Control Board Power

Due to the complex nature of the *Falcon's* controls it was necessary to develop a controller system that utilized ICs from different logic families. This meant that several voltage regulators were required to ensure each IC was powered appropriately. In addition, level translators were required to ensure that the ICs could reliably interface with each other. Figure 9 shows the schematic of the power systems. As seen in Figure 9 several safety features have been included to ensure that both the regulators and the ICs they supply are protected from both inductive spikes and improper wiring.

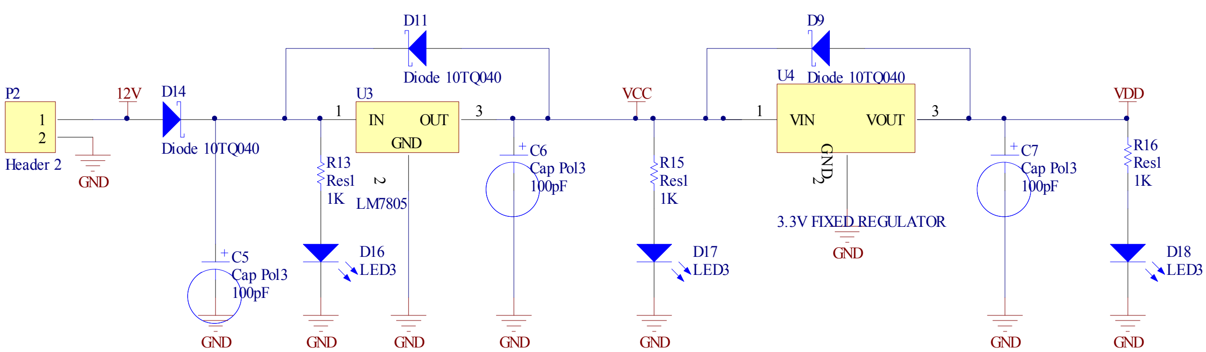


Figure 9: Power Systems

Uni-Directional Module

The circuit shown in Figure 10 was devised to control the motors only requiring a single polarity of voltage.

Since the micro-controller can only supply 3.3V_{DC} to its outputs a small signal NPN transistor has been used in a collector-follower configuration to drive an N-channel power MOSFET. The inclusion of the freewheeling diode ensures that the inductive spike generated when the MOSFET is switched off does not exceed the maximum voltage of the transistor. It should be noted that the selection of this diode is not a trivial one since the internal junction capacitance of the diode can also destroy the MOSFET. This is the reason that a Shockley diode has been used as the fly back diode and not a standard one.

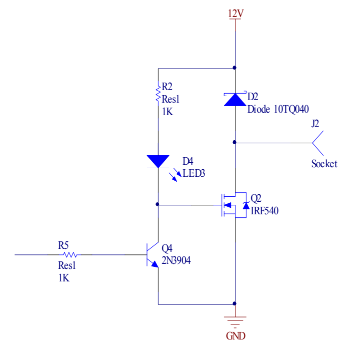


Figure 10: Unidirectional Driver

Bi-directional Modules

For motors that require a reverse polarity to operate the circuit shown in Figure 11 has been developed:

The heart of the bi-directional driver circuit is Silicon Micro Trend's (ST) VNH3SP30 H-Bridge IC. This IC is capable of sourcing up to 15A_{dc} at up to 40V_{dc} so it easily meets the modest requirements of our propulsion and tooling system. To ensure that at no time the H-Bridge can enter an invalid state an inverter circuit's input and outputs have been connected to the forward and reverse control pins respectively. In addition, indicator LEDs have been included for trouble shooting purposes.

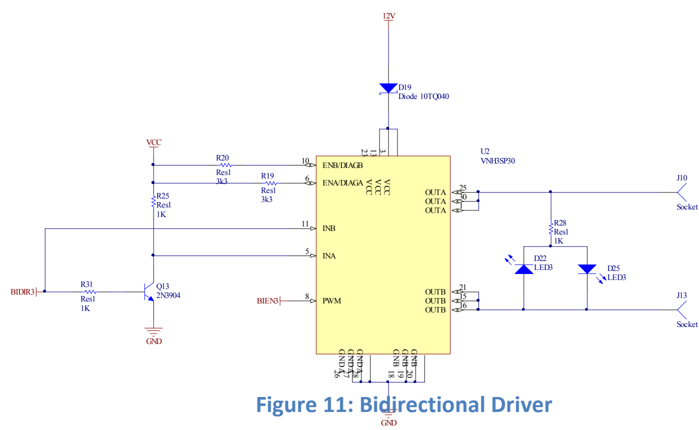


Figure 11: Bidirectional Driver

Video control modules

In order to ensure that as many camera angles as required are available to the *Falcon's* pilot, two 8 to 1 video multiplexers have been implemented. This means that any two cameras can be sent to the surface monitors by setting the control pins on each multiplexer independently as shown in Figure 12.

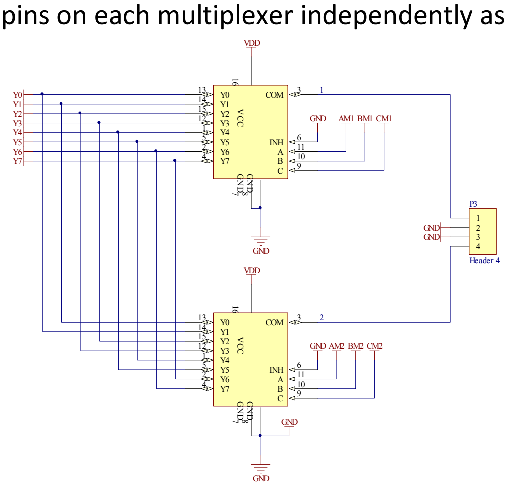


Figure 12: Video Multiplexer

Command Center & Dryside Electronics

The Command Centre, as seen in Figure 13, is the central unit that oversees power and data transfer with the ROV and provides the user interface. It is composed of a small form factor single board computer and three monitors mounted in a rifle carrying case. Two monitors are used to directly view the video signals from the ROV and the third is used by the computer to display additional information.

Figure 13: Command Center

Computer & Software

A Linux operating system installed on the single board computer is used to display a simple console program. The user inputs control signals to the console program via an Xbox 360 controller attached to the computer's USB port. The console program is a C++ based program that can communicate to the ROV via serial port. The communication system uses the rs-422 protocol, chosen because the communication signals use differential signalling. This type of signalling is robust enough to withstand line noise and can be used for long distance communications – necessary for our 20m tether system. As described below in *Challenges Faced,* the team abandoned a complex distributed software and control system in favour of an extremely simple software routine that communicates with the onboard electronics described above in *Onboard Electronics*. The simplified software system operates as seen in Figure 14.

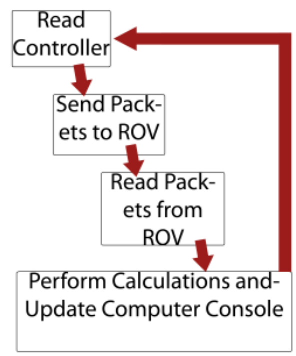


Figure 14: Software Flow

Power & Safety

The power source for the ROV enters the command center at $48V_{DC}$ and is routed through a 40 Amp circuit breaker and an Emergency Stop (ES) button circuit as seen in Figure 15. The ES circuit is designed such that if it loses power it will cause the $48V_{DC}$ circuit path to the $48V_{DC}$ ROV terminals to open. This is safer than the alternative where a lack of power would prevent the operator from being able to turn off the switch. Once the ES button is reset, the circuit is in normal operation again and the ROV can receive the $48V_{DC}$. A $120V_{AC}$ source is used to supply power to the computer and the monitors. The 120V enters a 270 Watt computer power supply which converts the $120V_{AC}$ into $12V_{DC}$ to power the CPU and LCD monitors.

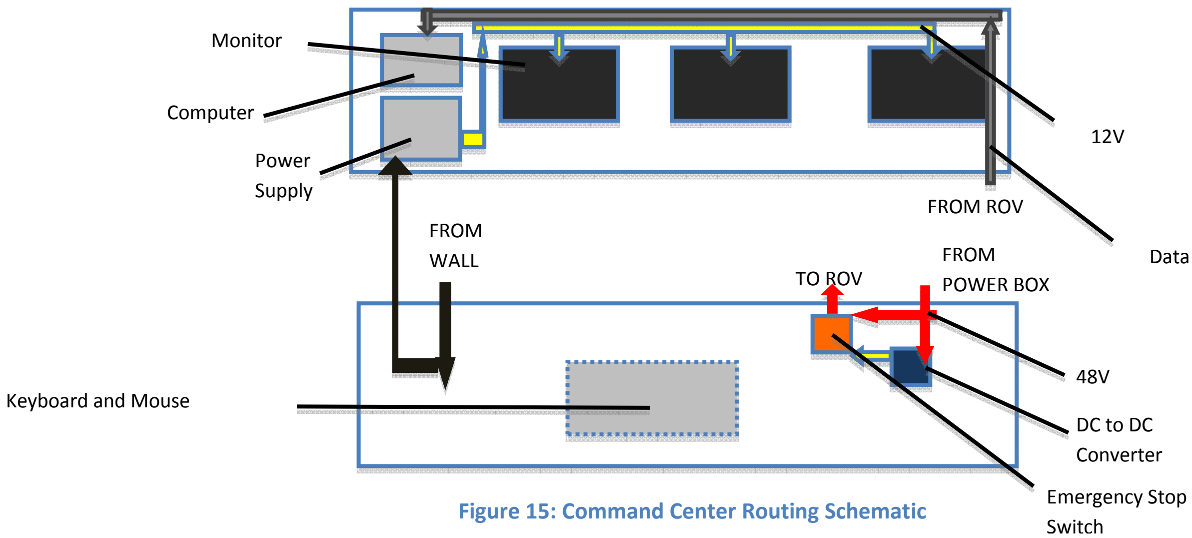


Figure 15: Command Center Routing Schematic

Instrumentation

The *Falcon* contains two major instrumentation packages:

1. A Temperature Sensor
2. A two dimensional phased array of Hydro-phones

Temperature Sensor

In order ensure accurate temperature measurement the Privateers opted to use a thermistor. A thermistor is simple device that will change its internal resistance based on temperature. By placing the device in series with a resistor it is possible to read a voltage that is proportional to the temperature. Equation 2 details the output voltage:

$$V_o = \frac{R_{series} \cdot V_{dd}}{R_{series} + R_{thermistor}}$$

Equation 2: Output Voltage

This voltage is fed through an op-amp buffer with that has had its input offset voltage set to zero to ensure there is a minimal measurement effect on the output voltage. The output of the buffer is then read by the on board micro-controllers 10 bit ADC. It was found that this gives extremely accurate readings of temperature.

Phased Array

By far the most difficult task in this year's mission is that of the rumbling vent. In order to accomplish this portion of the mission the Privateers have commandeered a pair of hydro-phones in order to construct a 2 dimensional phased array.

The basic principle of operation of the phased array is that by sampling a plane wave at two separate points separated by no more than ¼ wave lengths it is possible to determine by the phase difference of the samples the orientation of the points with respect to the direction of wave propagation. Although it is possible to pinpoint a source with extreme accuracy using a multi-dimensional phased array, it was decided that since the privateers pilot only needed to select between three sites, a two dimensional array was all that was required. To determine which site is rumbling the *Falcon* needs to find the site that has the minimum phase shift between hydro-phones when facing it.

In order to determine the phase and frequency of the given vent site a fast Fourier transform is performed on each sample set that has been collected. Once the transform is completed the resulting sets of complex coefficients are examined to find the 10 with the greatest magnitude. These coefficients are then transmitted to the surface along with the frequency that they correspond to. Once on the surface the main control computer simply converts the complex coefficients into both magnitude and phase for the pilot to interpret.

Power Box

The purpose of the Power Supply Box, seen in Figure 17, is to provide a $48V_{DC}$ source to use to test the ROV before the competition. The box provides a parallel charging circuit for its 8 batteries when the box is plugged into $120V_{AC}$, as well as safety features such as an emergency stop button and a 40 Amp circuit breaker.

The top layer of the box is the user interface, as seen in Figure 16. It contains an ammeter, voltmeter, two $48V_{DC}$ terminals, and a key switch controlling power to the 48V terminals. It also has safety features such as a 40 Amp breaker and an emergency stop circuit.

The middle and bottom layers consist of a $12V_{DC}$ battery charger, nine relays, and eight $12V_{DC}$ batteries. When the box is plugged in to the wall, $120V_{AC}$ energizes the charger and a laptop adapter, which outputs $9V_{DC}$ to energize the eight relays switching the batteries to a parallel connection with respect to the charger. Two PC fans running off $12V_{DC}$ turn on automatically during the charge cycle. The wiring diagram for one of the two four-battery banks can be seen in Figure 16.

Figure 17: Power Box

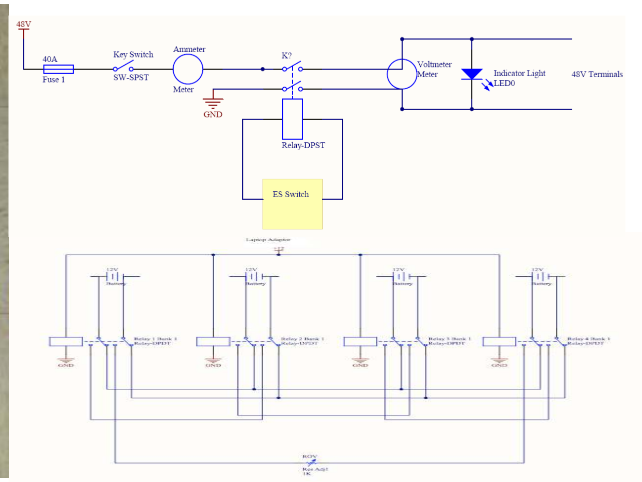


Figure 16: Box Top and Battery Schematics

The Power Supply Box is based on a model designed by the Privateers last year. Last year's box outputted data and power in one chord and provided the option of connecting to an external 48V source. The main concerns with the previous power supply box were short running time and noise in the data due to interference with the nearby power components.

This year the box was improved upon in that the box only deals with power. As previously mentioned, the command center deals with all data. This reduces noise in the *Falcon's* data lines. In addition, physically smaller but electrically comparable batteries were purchased in order to fit an additional bank of four batteries to provide a longer runtime.

Vision System

The *Falcon's* eyes remain largely unchanged from last year: we have mounted four of the small FishTV underwater cameras used in previous competition. Our main improvement has been to install three additional wide-angle (two 90° and one 120°) cameras which brings the craft to a total of seven video feeds. The new wide-angle cameras provide excellent range of view for piloting while the compact FishTVs are dedicated to tooling display.

Figure 18: Camera

Tools

The *Aluminium Falcon's* unique tooling systems were designed to allow the ROV pilot to accomplish the mission tasks with minimum manoeuvring in order to conserve time.

Elevator System

A main objective of the team was to create a tooling system that was able to accomplish all elevator-related Task #1 items in one motion. A power-screw driven assembly was created to simultaneously pull both pins and grip the HRH. This works in combination with a gripper claw that retrieves the T-connector. As seen in Figure 19 and Figure 20, these tools integrated into the ROV's frame in such a way that all tasks (pull pins, lift HRH, grab connector) may be accomplished without any repositioning of the ROV.

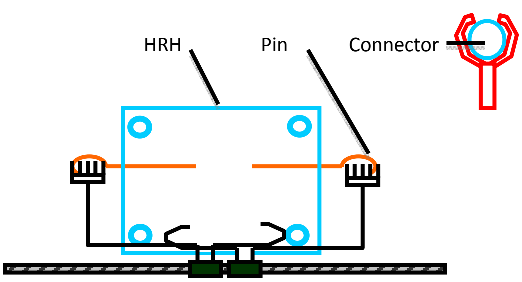


Figure 19: Elevator Approach

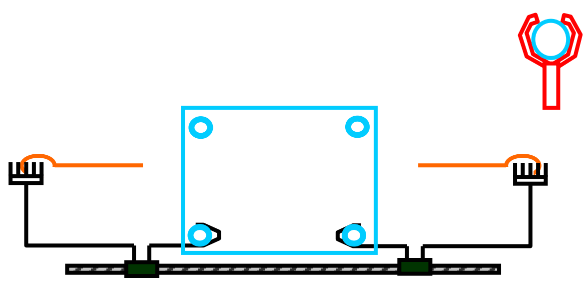


Figure 20: Elevator Pin Pulling and HRH Gripping

Pin Puller

The major design goal was to make a device that could pull out both J-bolt pins simultaneously. Several designs were prototyped, including a chain-driven hook system and a set of reciprocating teeth. The issue with both these designs was that two distinct actuation systems would be required, one for each pin. The final solution – a turnbuckle type power screw with left/right threading – was chosen because it was reliable and only required one actuator to remove both pins. Once the team saw how effectively the power screw operated, it was decided to add two additional gripping rods that would grab the HRH as the pins were being pulled out. The final design of the tool, seen in Figure 21, is based on a left/right thread steel power screw with runner blocks having left/right nuts pressed into them and mated to the power screw. The assembly slides on an aluminium channel and is driven by a $12V_{DC}$ motor and custom aluminium gears that give a stroke time of approximately 2 seconds. The blocks each have a pair of pin pulling forks and HRH grippers to mate with the appropriate mission props.

Figure 21: Pin Puller

Gripper

The design requirements for the gripper were a simple and light system that could be easily mounted to any location on the frame. An automobile door lock motor was chosen due to its integrated gearbox and proven water resistance. The gripper itself, seen in Figure 22, was designed to be able to grab the connector in any orientation, reducing the necessity for ROV repositioning. Like many of our tools, the gripper was modelled by team members using SolidEdge and printed using a rapid prototyper unit.

Figure 22: Gripper

Combine

The tool for collecting crustacean samples has been affectionately dubbed “the combine”. It consists of a brush mounted to the side of the ROV that sweeps the crustaceans from their hooks into a holding box. A passive design that simply used rubber fingers to dislodge the crustaceans from their mounts was prototyped but proved too unreliable. The original concept of the “combine” was an external box and brush that would be self contained and able to mount to the back of the ROV. The final design, seen in Figure 23, ended up being completely integrated into the frame of the ROV to minimize its physical footprint. The brush is constructed of three toilet brushes pieced together on a machined aluminium shaft. It is driven by a worm gear at approximately one revolution per second and rotates towards the box on top, which results in the crustaceans being swept up off the hooks and into the holding box. An aluminium panel spans the bottom of the brush to ensure that crustaceans don’t rotate back out of the box. The holding box is made of wire mesh and is inset to the frame. It has a Velcro hatch on the top that opens to allow removal of collected specimens.

Figure 23: Combine Brush and Cage

Temperature Probe

The temperature probe tool is comprised of two pieces: a fixed hollow cylinder with the temperature probe in the center, and an inside sliding cylinder that flares into a cone at the bottom. Four splines are used to keep the pieces on track and a set screw in a running track prevents the two pieces from separating. When the ROV is piloted into the tower prop, the cone will close around the opening and then slide back into the stationary piece, guiding the probe well inside the vent opening. The final version of the tool, seen in Figure 24, was created using rapid prototyping, incorporating a single mounting bracket to allow for the tool's angle to be set at will. While the original idea was to have the tool loaded with a spring, testing on the ROV prototype demonstrated that the spring was providing too much resistance, and thus it was decided to allow the tool to simply move freely instead.

Figure 24: Temperature Probe

Spire Collector

Several spire collector devices were prototyped, including a gripper such as the one used for the T-connector, a passive spring-based catch system, and a passive "wipe-top dispenser" pie-shaped rubber disk. The 'wipe-dispenser' design, as seen in Figure 25, was chosen because it worked reliably, was simple, and required no actuation. Several generations of collector were created until the design was perfected. The final version uses a three inch diameter tube with a single layer of foam/glove material on the bottom for large spires and a stiffer double layer on top for smaller spires.

Figure 25: Spire Collector

Agar Collector

The most important design requirement for the ROV's agar collection system was one that is both fast and requires as little driver attention as possible. To accomplish this, a custom one-way "check-valve" collector unit was developed. The square bottom profile is dimensioned such that it is small enough to be vertically inserted down through the entire depth of the agar dish. The two doors on the bottom of the unit are hinged such that they open upward inside the box but only drop as far as level with the bottom. This produces a check-valve effect when the unit is driven down into the agar: the hinges open up to allow agar to fill the unit, but as the unit is removed the weight of the agar inside forces the doors shut, trapping the agar inside. The unit is mounted to the bottom of the ROV via wingnuts: this makes it easy to remove the unit to submit the agar to the judges for inspection.



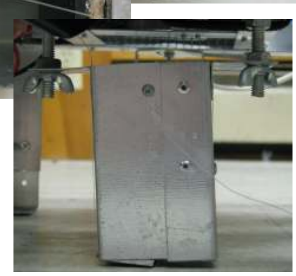


Figure 26: Agar Collector

Challenges Faced

A challenge faced throughout the year was the design of the *Falcon's* control system, which was originally designed with modularity in mind. This would allow us to add and remove modules as desired.

A prototype system was designed by team members, but during the by-hand assembly and testing we found noise on the Serial peripheral interface (SPI) bus was great enough to interfere with data transfer to the motor controllers. We attempted a number of possible solutions, including shielding and different cable configurations, as well as redundant data transmission to overcome the lost or corrupt data. It was concluded that SPI specification was simply not designed to perform well in long runs of cable, and was more suited for short traces on circuit boards. Therefore, another solution was required.

The master microcontroller board was completely redesigned to incorporate the motor controllers and other peripheral devices as a single unit. This would both keep wiring simple and increase noise immunity, providing the *Falcon* with the reliable control system it requires.

Troubleshooting Techniques

Throughout the year the Privateers' crew became familiar with troubleshooting techniques the hard way as the realities of robotics and vehicular testing became apparent. One particularly harrowing moment came during the most important event before the competition itself: the competency test. Previous to the competency day, the crew had tested the *Falcon* without issue several times, giving us confidence in its ability to quickly complete the test. As we prepared to complete the mission, however, all control was lost. Through a series of physical tests we determined the following:

- Control worked perfectly when the craft was out of the water.
- Control worked perfectly when the craft was in our testing tank.
- Control did not work at all when the craft was in the competency test pool.
- Control stopped working as soon as one of the controller modules contacted the pool water.

We combined this analysis with basic chemistry to arrive at the conclusion that the higher conductivity of the pool water as compared to our test tank water due to the chlorinated pool water caused a short within the distributed control system. Our temporary solution was to use a hardwired switchbox to pass competency while we directed our subsequent efforts into the development of a hardened control system.

Future Improvements

Since its inception three years ago, the team's size has grown from a half dozen to nineteen student members. While its rapid growth has allowed for far more man-hours to be devoted to the project as a whole, it has caused some problems with communication. For next year's team, stronger and more frequent communication is a priority. The best improvement that we see can be made would be the addition of a team log book in which details of each and every construction meeting will be recorded. The benefits of such an arrangement are threefold. First, members absent from a meeting can bring themselves up to speed without fear of anything being missed. Second, creating the final report will become much easier with an organized timeline of our design and prototyping process. Finally, the log book is a lasting record that can serve as inspiration to future teams' designs and proof of the team's dedication to potential sponsors.

Lessons Learned and Skills Gained

Throughout our team's year together, we have all learned more lessons and gained more skills than there is space here to chronicle.

An important technical skill learned by many of the crew involved with the *Falcon's* mechanical systems was the practical use of 3D CAD modelling applications such as SolidWorks. As noted in previous sections, key components of the propulsion and tooling systems were designed using CAD and created with a 3D printer. This construction method served to increase CAD modelling abilities within the team and to significantly broaden team members' understanding of prototyping techniques.

An interpersonal skill gained by the team's leadership was the importance of clear role assignments. In previous years, team members simply congregated during meeting times to construct whatever needed to be done at the time. While this approach works for very small teams, it is inefficient as the crew size increases. We soon realized that the best way to run the project was to clearly assign tasks and projects to individual and small groups of crew members: this both ensures that every task is being accomplished and that everyone has a clear goal that they can work toward.

Reflections

The entire Privateer's crew has come out of this venture with new skills, ideas, and friendships. Below are the personal reflections of one new recruit and one old hand.

Irenee Jantz-Lee (First year as a member)

"Surrounded by a perceived infinity of people who had been programming since the age of five or soldering circuit boards in their spare time, I was both excited and worried about entering into Electrical Engineering. Thus I joined the ROV team. I learned about all sorts of things: soldering, wire gauges, schematics, transistors. When my Electrical Design professor asked the class who had seen the inside of a computer, the majority of people were on the ROV team, and I was among them. The experience I have gained has given me confidence in my field, and in my decision to become an Electrical Engineer."

Timothy Pohajdak (Third year as a member)

"I learned a lot from this project, mostly about the virtues of planning with regards to its effect on project management. This year, our increased scheduling and more direct assignment of tasks on a weekly basis made our ROV come together far more smoothly than it did in previous years. I also found that increased testing made a huge difference in our ROV - the ability to test our ROV underwater made a large difference in increasing the speed of our design -> building -> test -> redesign cycle, allowing for more iterations within a given span."

Lo'ihi Seamount

The Lo'ihi seamount is an important volcanic feature part of the Hawaiian-Emperor seamount chain. The chain is off of the southeast section of Hawaii and is considered the youngest of the volcanoes in

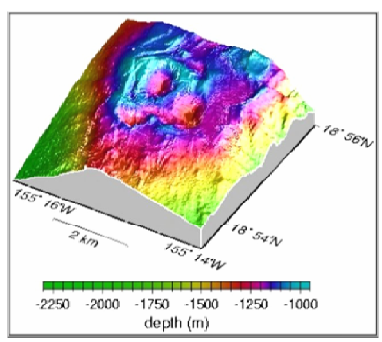


Figure 27: Seamount

the chain. Lo'ihi stands 3000 meters above the ocean floor and is larger than Mount St. Helens before it erupted in 1980[1].

The Lo'ihi seamount the only known preshield volcano in the area, making the scientific study of it important for the understanding of its older surrounding cousins. Lo'ihi also resides upon a more ancient volcano's flank, Mount Loa[2]. Lo'ihi's summit is a caldera depression with three craters in the most southern part of the depression, as seen in Figure 27[3]. It is from this long caldera that the volcano takes its name – Lo'ihi is Hawaiian for 'long'[4]. The most recent depression used to be vents that were named Pele's Vents until 1996's[5] earthquake activity in which they collapsed forming a 600 meter wide depression that was in turn named Pele's Pit[6].

In 1996 a series of up to 4070 earthquakes impacted Lo'ihi, ranging from small tremors to quakes greater than 5 on the Richter scale. Pele's Vents were studied in depth by Hawaii Undersea Research Laboratory before their collapse. They studied the vents by taking samples of the minerals that flowed from these vents. They also studied the plumes of the vents and found they changed radically over the years[7]. The vents have a high concentration of CO_2 and iron which creates a perfect climate for iron-oxidizing bacteria. The temperatures of these vents were 30 degrees Celsius[8]. The ROV mission for temperature readings replicates the work done on these vents before their destruction.

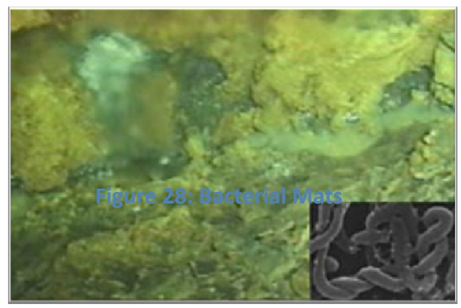


Figure 28: Bacterial Mats

In 1999 another trip to Lo'ihi discovered new jelly-like organisms (seen in Figure 28[9]) that are part of the microbial mats that were sampled in Lo'ihi. The trip was funded by The National Science Foundation[10]. These microbial mats are similar to those that we must collect in the missions for the ROV. Two other invertebrates found in and around the vents were a bresiliid shrimp and pogonophoran worm. However, since the 1996 earthquake these two species have not been located and there is speculation that the earthquake severely reduced their numbers, if not outright led to their extinction.[11]. Another of the competition missions is to collect these worms in a cave similar to the missions that collected the original samples.

The Lo'ihi seamount is an important site for research into underwater organisms and submarine volcanoes. The important organisms that are found here are microbial mats, cutthroat eels and worms that live in and around the vents. The seamount is also very important to understanding preshield volcanoes in the Hawaiian Emperor Chain and is a model for the older volcanoes in the area. The missions for the competition model many of the tasks that were faced by researchers in their quest to understand the unique system that the Lo'ihi seamount has created.

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[1] Hawaiian Center for Volcanology - *Lo'ihi Volcano.* http://www.soest.hawaii.edu/GG/HCV/loihi.html
[2] Wikipedia - *Lo'ihi Seamount*. http://en.wikipedia.org/wiki/Loihi_Seamount
[3] HVO - *Three-dimensional bathymetric map of the southernmost two-thirds of the Lo'ihi summit platform.* http://www.volcano.si.edu/world/volcano.cfm?vnum=1302-00-&volpage=var

[4] Hawaiian Volcano Observatory - *Lo`ihi Seamount*, Hawaii's Youngest Submarine Volcano. http://hvo.wr.usgs.gov/volcanoes/loihi/
[5] Wikipedia - Lo'ihi
[6] Hawaiian Volcano Observatory
[7] Alexander Malahoff. NOAA Research - *Loihi Submarine Volcano: A unique, natural extremophile laboratory.* http://www.oar.noaa.gov/spotlite/archive/spot_loihi.html
[8] Wikipedia - Lo'ihi
[9] NOAA - 160 degree Celsius vent with jelly-like bacterial mat. http://www.nurp.noaa.gov/Spotlight/Loihi.htm
[10] Alexander Malahoff - Loihi
[11] Wikipedia - Lo'ihi

Appendix A – Vector Propulsion System Performance

In order to accurately assess whether modifications or alternatives to the vector propulsion system made in future years are positive ones, it is important to quantify the current system's performance. The following is a brief analysis of the losses caused by the tubing system, as well as the theoretical thrust force obtained from the system as a whole driving both forwards and sideways.

Before any analysis could be made, it was important to gather the data necessary for our calculations, both through real life measurement and through various resources in the case of constants for water. Constant values used are as listed in Table 1.

Constant	**Value**	**Source**
Bilge pump intake area (A_1)	3.88 E – 4 m^2	Physical measurement
Nozzle output area (A_2)	1.538 E – 4 m^2	Physical measurement
Nozzle output diameter (D_2)	0.168 m	Physical measurement
Roughness of Tubing (ε)	0.001587 m	Physical measurement
Diameter of Tubing (D_T)	0.0381 m	Physical measurement
Specific Weight of Water (γ)	9.8 kN/m^3	Fundamentals of Fluid Mechanics 6th Ed
Density of Water (ρ)	999 kg/m^3	Fundamentals of Fluid Mechanics 6th Ed
Dynamic viscosity of water(μ)	1.002 E – 3 $N{\cdot}s/m^2$	Engineering Toolbox
Length of Tubing (L_T)	0.4097 m	Physical measurement
Minor Loss Coefficient of Nozzle (k_1)	1.488	Mechanics of Fluids 3rd Ed
Minor Loss Coefficient of Joiner (k_2)	~0.09	Westerndynamics.com

Table 1: Constants

In order to determine the velocity with which water exited the nozzle, the following setup was established as in Figure 29. The jet reached a total height of 1.524m. Bernoulli's equation was applied between point n at the nozzle's exit (where height and pressure equal zero) and point 2 at the top of the jet (where velocity and pressure equal zero)

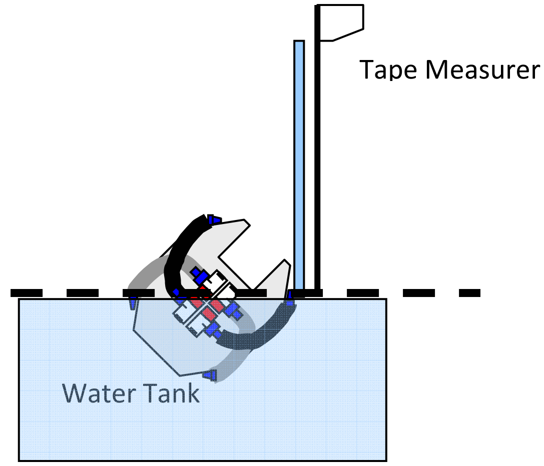

Figure 29: Experimental Setup

Calculations

$$V_n^2/2g + \cancel{P_n/\gamma} + \cancel{z_n} = \cancel{V_2^2/2g} + \cancel{P_2/\gamma} + z_2$$

$\mathbf{V_n = 5.468\ m/s}$ (approximately 20km/h)

From the velocity, the continuity equation was used to obtain the flowrate of the system.

$$Q = V_n A_1$$
$$\mathbf{Q = 0.002122\ m^3/s}$$

Because the bilge pumps are identical, it can be assumed that $Q_{bilge} = 1/2Q$

The velocity was also used to obtain the Reynold's number for the flow

$$Re = \rho V_n D_2/\mu \approx 819\ 000$$

This Reynolds number suggests that the flow is turbulent, which is supported by our qualitative observation of the free jet when the experiment was carried out.

The total head loss was obtained by setting

$$h_T = (\ f(L_T/D_T) + k_2)V^2_{tubing}/2g + k_1 V_n^2/2g$$

where f is the friction factor found using a Moody diagram. Note that k_2 is an approximate value. As the total cross sectional area into the joiner is approximately equal to the total cross sectional area out, we were able to approximate the system as a mitre bend with an angle equal to 10˚. Thus the total head *loss is:*

$$h_L = (\ f(L_T/D_T) + k_2)\ (Q/((0.25\pi D_T^2))^2/2g + (k_1 V_n^2/2g)$$
$$h_L = 0.1392\ m + 2.2803\ m$$
$$\mathbf{h_L = 2.4195\ m}$$

The head loss is quite substantial, which leaves a good deal of room for improvement in later years. The overwhelming majority of this loss comes from the nozzle. While some loss is unavoidable with nozzles in general, minimizing this loss should be a priority for next year's propulsion team.